HYDROCYCLONE/MAXIMUM DENSITY SEPARATOR
DEMONSTRATION PROJECT AT FT. MYERS BEACH, FLORIDA
SEPTEMBER 21-23, 1998

BY

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BACKGROUND

The U.S. Army Corps of Engineers, Jacksonville District, is continuing its interest in expanding hydrocyclone technology and associated in-house capabilities in its navigation and beach nourishment missions. Initial hydrocyclone efforts included a fact finding workshop during January 1994 bringing together representatives from the navigation dredging industry (Bean Dredging and Great Lakes Dredge and Dock), the hydrocyclone industry (Met-Pro and Krebs), the U.S. Army Corps of Engineers (representatives from the Jacksonville District, Waterways Experiment Station, Coastal Engineering Research Center, and Los Angeles District) and the State (Bureau of Beaches and Coastal Systems, Florida Department of Environmental Protection, FDEP, formerly Division of Beaches & Shores, Florida Department of Natural Resources).

Findings at this workshop resulted in a conceptual plan using hydrocyclone technology and processing for separating beach quality sand material from silt material for future maintenance dredging operations at Canaveral Harbor (Heibel, Granat, and Wolff, 1994, and Heibel, Granat, and Wolff 1995). An unanswered issue was the disposition of the resulting fine-grained slurry overflow. Further development and implementation of this conceptual plan was not pursued since it was not the least cost disposal option and the sponsor was not interested in paying the added cost.

During April 1997, a closed-loop, laboratory, bench-top study was conducted at Met-Pro Supply, Inc. (Bartow, Florida), using a six-inch maximum density separator (MDS) hydrocyclone and five contaminated Miami River sediment samples. Follow-on flocculation testing was also undertaken at that time at the University of Florida. The paper by Granat (1998) summarizes that work and provides a detailed explanation of the MDS operation.

HYDROCYCLONE/MAXIMUM DENSITY SEPARATOR OPERATION

A hydrocylone is a rather simple, highly energy efficient sizing device with no moving internal parts. It has been used for the past fifty or so years in the mineral processing and mining industry. It uses centrifugal forces to separate coarse- and fine-grained material in a water-solids slurry. Recent advancements in this technology, i.e., keeping the slurry under negative pressure, creating a MDS, have expanded processing capabilities by providing a means of achieving a constant percent solids underflow instead of the traditional constant volume normally produced.

Figure 1 illustrates a typical MDS. In operation, a slurry mixture is introduced into the MDS slurry feed chamber under pressure. The tangential force causes the slurry to rotate at a high angular velocity, forcing coarser heavy particles to the side walls where they continue downward with increasing velocity to the bottom of the cone section of the hydrocyclone. This material then exits through the apex as a denser, higher percent solids material called the underflow. The cyclonic flow in the hydrocyclone creates a centrally located low pressure vortex where the lighter, lower density, finer-grained sediments and water flows upward and exits the top of the hydrocylone through the vortex finder. This finer-grained, reduced percent solids slurry is called the overflow. The paper by Granat (1998) describes the hydrocyclone and MDS modifications in more detail.

FT. MYERS DEMONSTRATION PROJECT

The present report documents and summarizes the District’s most recent work in the MDS evaluation process, a demonstration project conducted on site at Ft. Myers Beach, Florida, utilizing the closed-loop six-inch MDS cyclone and a production 12-inch MDS hydrocyclone fed by a slurry pump simulating an actual dredging operation. The primary purpose of this demonstration project was to first demonstrate the quality (visual color) of the Ft. Myers derived sand underflow material (closed loop six-inch MDS) and then to examine the resulting grain-size distribution of the sand underflow from the slurry-pump-fed 12-inch MDS hydrocyclone. Results from these tests were successful and provide supporting documentation for a permit request to undertake actual production operation at the Ft. Myers maintenance dredging project using a 14-inch hydraulic pipeline dredging plant to feed a bank of 24-inch MDS hydrocyclones.

Two scopes of work were developed for this demonstration project, one for the actual MDS operation testing demonstration and the other for the chemical and physical characterization of materials collected from bulk, underflow, and overflow samples. Both scopes of work were provided to FDEP for review and comment. Comments were incorporated in the scopes of work prior to completing contract arrangements. Met-Pro was awarded the MDS hydrocyclone work and PPB Laboratories (Gainesville, Florida) and their subcontractors were awarded the chemical and physical characterization work, including sampling, analyses, and reporting. Separate reports resulting from these contracts were prepared. A summary video documentation of the field efforts conducted at Ft Myers, Florida, during September 21-23, 1998, was prepared.

APPURTANENCES

Figure 2 illustrates a location map of the general study area including the location of the two samples collected for testing in the closed-loop six-inch MDS bench-top apparatus, one at the edge of the channel, approximately three hundred feet to the east of the intersection of Cuts 7 and 8, and the other adjacent to the channel in Cut 8, in the basin adjacent to the Ft. Myers County boat ramp. This is the same basin from which the slurry pump dredged the material for the 12-inch MDS demonstration testing. The MDS operating area and the 30-foot by 80-foot retention area built by the County for storing the slurry overflow is also indicated on Figure 2.

Prior to processing through the six-inch MDS cyclone, each of the samples were screened to remove shell and other particles larger than about 0.25 inch in diameter to avoid clogging the apex (underflow discharge) of the six-inch MDS. The screened sample was then placed in the mixing tank and mixed with basin water to obtain an approximate 10- to 15-percent solids slurry. This mixture was then processed in the closed-loop six-inch MDS to provide a very fine sand-sized underflow and a silt slurry overflow. Figure 3 illustrates bulk (pre-MDS processed), and post-MDS processed underflow, and overflow samples from the basin area. Figure 4 illustrates the resulting sand underflow compared to the screened bulk sediment from the channel sample. As illustrated, the six-inch MDS processing of Ft. Myers sediment samples results in a clean, visually attractive, sand underflow. Based on a visual classification of this sandy material the produced sand underflow would be characterized as a gley N 7/0 (light gray) on the Munsell soil color classification system. The pre-processed material would be characterized as a gley N 4/0 (dark gray) or darker.

The barge used as the staging area for the dredging operation adjacent to the County boat ramp area is illustrated in Figure 5. A close up of the barge and the six-inch slurry pump is illustrated in Figure 6. Figure 7 shows the diked MDS operating area with the six-inch closed-loop MDS setup in the foreground and the 12-inch MDS setup in the background, in front of part of the retention site dike. Figure 8 shows a close-up of each device.

In the six-inch closed-loop operation, sediments to be processed are introduced and diluted with site water in the mixing tank. Materials are continuously recycled in this configuration. In the 12-inch MDS operation, slurry material is pumped from the dredging area to the screened scalping device, the raised blue sloping device shown in Figure 8. Material finer than 0.5 inch falls through the scalping screen and is gravity fed to the automatic level control (ALC) sump (Figure 9). The over-sized material, generally shells and trash, collects on the screen for later disposal.

Figure 9 illustrates the two interconnected compartments of the ALC. The finer than 0.5-inch scalped sediment is introduced to the ALC into the feed compartment, on the right side of the ALC. This feed material is then pumped to the MDS for processing. The post-processed underflow sand is separated from the slurry by centrifugal force and exits through the apex at the bottom of the MDS and accumulates on the ground. The remaining fine-grained low solids slurry overflow is fed back to the ALC into the overflow compartment. This slurry normally overflows the weir where it is discharged to the disposal or retention site. If insufficient slurry volume is delivered from the dredge to maintain the desired head in the feed compartment, the low solids MDS overflow slurry can flow back from the ALC overflow compartment into the feed compartment through a slot in the bottom of the connecting wall to compensate and maintain the necessary head to satisfy the MDS pump. In this manner, the ALC ensures the desired head and slurry feed to the MDS.

Figure 10 illustrates a portion of the retention site showing the slurry discharge from the 12-inch MDS overflow into the retention site. Figure 11 illustrates the approximately four-foot high pile of beach quality sand underflow produced after about four hours of processing time.

EQUIPMENT AND SAMPLING LIMITATIONS

A discussion of equipment and sampling limitations is in order before results are presented and described. A 12-inch MDS hydrocyclone was used in the demonstration project for ease of operation and economy of scale. A 24-inch MDS hydrocyclone would be the preferred processing plant for a sand/silt split, however, the volumes of material to be processed and the resulting underflow and overflow volumes would require a much larger operation including a larger pumping plant and retention disposal site.

A larger than normal (5.0-inch instead of the normal 3.75-inch) vortex finder (the MDS internal discharge point for the slurry overflow) and a lower pressure were used in the 12-inch MDS system to produce a split more similar to a 24-inch MDS system (Met-Pro, 1998). This modified system was used in an attempt to produce a similar coarser grain-size distribution for the produced underflow material. A standard 12-inch MDS would normally make a sharp size split at around 270 to 325 mesh (53 to 44 microns) instead of the desired 200 mesh (74 microns). As a result of these modifications, the sharpness of separation is adversely effected and some plus 200 mesh fine sand would be expected in the overflow. It should also be noted that plus 200 mesh shell fragments and organic solids would also report to the overflow because of shape and reduced specific gravity. The MDS separation is based on hydraulic characteristics while a standard sieve analysis is based on mechanical shape and size characteristics, adding to resulting size differences, as discussed later.

Another primary equipment modification/limitation was the type of dredge pump used to feed the MDS system. A horizontal hydraulic driven slurry pump was modified with a water jet manifold attached to the bottom of the pump and was suspended from a crane (see Figure 6). This apparatus was lowered to the basin bed and swung through the water column to simulate a dredging plant operation. This was a “compromise dredging system” to keep project costs within budget limitations. This system seldom produced the desired uniform feed and often resulted in wide fluctuations from occasional surges of high percent solids to the receiving sump, potentially exceeding the capacity of the 12-inch MDS cyclone apex (underflow discharge), to some periods of almost clear water at other times. These wide swings in solids help demonstrate the flexibility of the combined ALC-MDS system. As with any dredging operation, efficient dredge production rates require experience and expertise in lever and feed control, all of which were lacking at the beginning of this demonstration project. As the demonstration continued, experience and control were improved as was the resulting sand production.

A final limitation that impacts the demonstration results is the non-synoptic sampling scheme followed. Again due to logistics and budget limitations, sampling was not performed at similar times so a material balance between the bulk, underflow and overflow measurements is not possible. In addition, due to logistics, sediment sampling at the ALC/MDS location was not coordinated with optimum slurry pump operation or location. Sampling may have occurred during periods of pump raising and lowering or during periods of intensive/extensive jetting action resulting in anomalous characterization of the sediment make-up. As indicated in the video documentation and discussed above, wide variations and fluctuations in production were experienced with some periods of time with little to no sand underflow (simply water and suspended sediments), to periods of time with about equal amounts of underflow and overflow production, to some periods of time with low fine-grained loads.

RESULTS

As discussed above, three non-synoptic samples each of the bulk, underflow, and overflow samples were obtained and analyzed (total of nine samples). Since these samples were not collected synoptically (they were collected at different periods of time and production rates), a material balance can not be performed. Results obtained from the physical and chemical analyses of the 12-inch MDS processing are provided in detail in the contractor report (PPB, 1998). Table 1 summarizes the grain-size analysis results from the three bulk, underflow, and overflow samples while Table 2 summarizes associated interface settling rates. Table 3 summarizes the associated chemical analysis results.

The physical results will be examined first, followed by the chemical analysis results. The three bulk samples were collected from the basin adjacent to the Lee County boat ramp off San Carlos Avenue using a Van Veen surface sediment grab sampler. As indicated, based on a weight percentage, obtained samples ranged from 87.8 to 93.5 percent sand (12.2 to 9.7 percent silt) with an average of approximately 89.5 percent sand (10.5 percent silt). This low percentage of silt-sized particles appeared surprising based on visual assessment of other grab samples and pumped slurry observations (see associated video documentation). The basin area appears to be heterogeneous with varying pockets of silty-sand to sandy-silt grain-size populations. As indicated in the video documentation, at times the general dark black color of the slurry confirms areas of higher concentrations of organic-rich silty sediments, perhaps below the surface of the bed.

The sand underflow samples were collected from the resulting pile of sand under the 12-inch MDS stand (Figure 11). Based on sample results, the underflow material was found to have an average of less than 3 percent fine-grained material with the range varying from 2.2 to 3.0 percent silt-sized particles. With regard to the color of the underflow sand, similar color was obtained with the closed-loop 6-inch MDS processing of the channel sample (Figure 4) and the 12-inch slurry-pumped basin sample. The channel sample was collected in the area of the highest concentrations of silt-sized sediments, approximately 50 percent silt-sized sediments by weight.

The overflow samples, collected from the ALC discharge bin, were found to have the largest variations. The first sample (Sample 161340) was found to contain an impressive less than 10 percent sand (90.6 percent silt). The second sample (Sample 161341) was found to have almost 25 percent sand (approximately 75 percent silt), while the final sample was found to have approximately a 46 percent sand and 54 percent silt content. This high sand percentage is surprising and can be explained by several different or combination of reasons.

As explained above, the feed to the MDS from the slurry pump was not uniform and occasional surges of high percent solids was introduced to the receiving sump exceeding the capacity of the 12-inch MDS cyclone apex resulting in bypassing material to the overflow discharge. A better-controlled dredging operation would provide the desired more consistent feed to the MDS system. Another explanation could be the over-sized vortex finder and the reduced pressure in the operation of the 12-inch MDS, both resulting in reduced sharpness of separation. A final explanation could be the differences between the MDS separation that is based on hydraulic characteristics and the sieve grain-size analysis that is based on mechanical (size and shape) characteristics, as discussed below.

Figure 12 graphically summarizes the sediment grain-size distribution based on the mechanical sieve analysis in terms of the weight percent finer than the identified size class. As indicated, the three sand underflow samples are quite similar in their grain-size distribution and overlay each other. The three bulk samples also indicate little scatter, with only a slightly higher percentage of finer-grained sediments than the underflow samples. The slurry overflow samples indicate the largest fluctuations in their finer-grained constituents.

Figure 13 graphically summarizes the interface settling rate results based on sediment hydraulic characteristics. These results were obtained by mixing the same sediment sample used in the sieve analysis with water, then placing it into a 100 centimeter high graduated cylinder, and the distance of the interface between the clearer overlying water and the settled slurry was measured at selected times over a 24-hour period. As indicated, each of the three sample types were unique and naturally categorized into distinct groupings (bulk, underflow, and overflow).

The interface for the underflow samples quickly reached their final consolidation depth within about 1 minute of settling. The bulk samples, containing both sand and silt constituents settled at an intermediate rate between the underflow and overflow samples. The overflow settling rates indicated that little coarser-grained sands were included in these samples. The higher concentrations of coarser material indicated in the mechanical sieve analyses are thought to be associated with less dense and/or elongated shell and organic constituents that were mechanically characterized as coarser sand particles but are hydraulically characterized as finer grained sediments.

Chemical analyses were also performed on the samples. TCLP (Toxicity Characteristic Leaching Procedure) leachates from each of the nine sediment samples were analyzed for the following nine metals: aluminum, arsenic, barium, cadmium, chromium, lead, selenium, mercury, and silver. In addition, the three overflow samples were also analyzed for total metals content for the above metals. Table 3 summarizes the chemical results. As indicated, all obtained samples were orders of magnitude below regulatory TCLP levels. As expected, underflow samples generally had values lower than the bulk samples, while the overflow samples demonstrated highest levels of metals, but still well below TCLP levels of concern.

The pre-processed bulk samples and the MDS-processed underflow and overflow samples from the Ft. Myers Federal navigation project area were found to be well below regulatory TCLP levels with the derived sand underflow suitable for direct placement on the beach, providing desirable shoreline erosion protection. The slurry overflow material would be suitable for upland disposal into a reduced acreage disposal site, where it could be dewatered and then reworked, turning the site into a more fertile landside area. This hybrid dredging approach provides several enhanced benefits including desired shoreline protection, a reduced disposal site size requirement, and fertile soil.

SUMMARY AND RECOMMENDATIONS

An MDS/hydrocyclone demonstration project was successfully completed during 21-23 September 1998 at Ft. Myers Beach, Florida. The primary purpose of this demonstration was to examine the resulting visual color, grain-size makeup, and chemical (heavy metal) quality of a 12-inch MDS produced sand underflow and slurry overflow, fed by a water jet modified slurry pump simulating a typical dredging plant operation. The operation produced a visually attractive beach quality sand underflow and a slurry overflow that were well below regulatory TCLP metal levels of concern. Equipment and sampling limitations impacting results are also discussed.

Based on presented results, it is recommended that a hybrid MDS/hydrocyclone navigation channel maintenance dredging effort be conducted at the upcoming Ft. Myers Beach Federal navigation project. Permits should be approved to allow full implementation of this project with the obtained sand underflow discharged directly to the beach and the slurry overflow discharged to an upland disposal site for dewatering and eventual reworking into the disposal site. This hybrid dredging MDS processing approach would provide multiple benefits providing needed and desirable beach nourishment for shoreline protection, a reduced acreage upland disposal site requirement, and an enriched, more fertile disposal site soil.

TABLE 1. FT. MYERS MDS DEMONSTRATION PROJECT GRAIN-SIZE ANALYSIS SUMMARY

											PERCENT	
				PERCENT FINER								
	STATION ID	SAMPLE #	SIEVE #	4	10	20	40	60	140	200	SAND	SILT
			mm		2	0.84	0.42	0.25	0.105	0.074		
			phi		-1.00	0.25	1.25	2.00	3.25	3.75		
BULK	E-FMH98-	1 -	161334	100.0	99.8	99.6	98.9	94.6	17.2	9.7	90.3	9.7
	E-FMH98-	2 -	161335	100.0	99.6	99.4	98.6	94.6	18.9	9.5	90.5	9.5
	E-FMH98-	3 -	161336	100.0	100.0	99.9	99.5	96.0	22.2	12.2	87.8	12.2
UNDERFLOW												
	E-FMH98-	4 -	161337	100.0	99.7	99.3	98.3	94.2	12.0	2.5	97.5	2.5
	E-FMH98-	5 -	161338	100.0	99.7	99.1	97.8	92.9	11.9	3.0	97.0	3.0
	E-FMH98-	6 -	161339	99.8	99.3	98.7	97.6	94.0	11.5	2.2	97.6	2.2
OVERFLOW												
	E-FMH98-	7 -	161340	100.0	100.0	99.9	99.6	99.2	92.8	90.6	9.4	90.6
	E-FMH98-	8 -	161341	100.0	100.0	99.8	99.4	98.8	81.1	75.2	24.8	75.2
	E-FMH98-	9 -	161342	100.0	100.0	99.7	99.1	98.3	63.3	53.7	46.3	53.7

TABLE 2. FT. MYERS MDS DEMONSTRATION PROJECT INTERFACE SETTLING RATE SUMMARY, CM

DESCRIPTION	STATION	# - SAMP	0.1	0.5	1.0	2	5	10	15	30	60	120	180	240	300	1440
		TIME,MIN														
BULK (IN SITU GRAB SAMPLE)																
	E-FMH98-	1 - 161334	99.9	99.8	99.5	98.5	76.0	48.5	20.5	14.3	12.1	11.0	10.0	9.7	9.5	8.5
	E-FMH98-	2 - 161335	99.9	99.8	99.5	98.0	78.0	47.5	22.5	16.0	13.3	12.8	11.0	10.8	10.5	9.0
	E-FMH98-	3 - 161336	99.9	99.8	99.0	98.5	77.5	46.5	25.2	17.0	13.3	11.5	11.0	10.7	10.4	9.0
UNDERFLOW (MDS POST-PROCESSED)																
	E-FMH98-	4 - 161337	40.0	20.0	6.0	5.7	5.6	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
	E-FMH98-	5 - 161338	30.0	15.0	6.0	5.5	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4	5.4
	E-FMH98-	6 - 161339	32.0	18.0	6.5	5.6	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
OVERFLOW (MDS POST-PROCESSED)																
	E-FMH98-	7 - 161340	99.9	99.8	99.7	97.5	88.0	77.0	68.5	51.0	33.0	24.0	22.0	20.0	19.2	13.2
	E-FMH98-	8 - 161341	99.9	99.8	99.6	98.0	87.1	76.5	69.6	54.2	36.5	25.5	23.8	21.5	20.6	14.4
	E-FMH98-	9 - 161342	99.9	99.8	99.6	97.5	86.7	76.0	68.7	52.5	35.5	24.0	22.2	20.0	19.1	13.5

TABLE 3. FT. MYERS MDS DEMONSTRATION PROJECT CHEMICAL ANALYSIS SUMMARY (ug/L unless otherwise noted)

	STATION	SAMPLE #	% Solids	Aluminum	Arsenic	Barium	Cadmium	Chromium	Lead	Mercury	Selenium	Silver
TCLP REGULATORY LEVEL			NA	NA	5,000	100,000	1,000	5,000	5,000	200	1,000	5,000
BULK	E-FMH98-	1 - 1	70.0	151	2.7	374	1.4	7.0	8.0	<0.1	<2	<1.5
	E-FMH98-	2 - 1	69.1	<20	5.7	538	2.4	10.2	6.0	<0.1	<2	<1.5
	E-FMH98-	3 - 1	67.2	904	7.4	340	1.8	5.6	7.9	<0.1	<2	<1.5
UNDERFLO	E-FMH98-	4 - 1	84.2	658	<0.5	384	1.8	5.5	5.7	<0.1	<2	<1.5
	E-FMH98-	5 - 1	83.8	409	<0.5	360	1.5	4.1	3.6	<0.1	<2	<1.5
	E-FMH98-	6 - 1	82.9	512	1.4	361	1.7	2.8	4.4	<0.1	<2	<1.5
OVERFLOW	E-FMH98-	7 - 1	14.5	829	7.8	291	3.7	3.9	11.0	<0.1	<2	<1.5
	E-FMH98-	8 - 1	12.5	789	6.9	293	3.7	2.6	11.4	<0.1	<2	<1.5
	E-FMH98-	9 - 1	16.4	913	10.1	277	3.4	2.5	9.6	<0.1	<2	<1.5
SITE WAT												
	E-FMH98-	161343		368	0.5	18	0.5	2.0	1.0	0.1	2.0	0.3
OVERFLOW TOTAL METALS (ug/g dry we												
	E-FMH98-	7 - 1	14.5	19100	57.8	45.6	0.6	67.3	10.2	<0.2	38.0	0.4
	E-FMH98-	8 - 1	12.5	16300	60.2	40.3	0.3	49.2	7.2	<0.2	11.7	0.3
	E-FMH98-	9 - 1	16.4	13000	32.6	36.0	0.3	43.1	7.8	<0.2	5.8	0.4

ADVANTAGE: EASILY MODIFIED

The MET-PRO Maximum Density Separator is a versatile piece of equipment that can be easily modified in the field to meet changing conditions in the process stream. The three critical variables of any MDS can be modified as follows:

MAXIMUM DENSITY SEPARATOR

1. • ***INLET AREA:*** *Cross sectional areas can be changed to modify the velocity and capacity requirements by adding or subtracting inlet inserts, made of the same material as the separator lining, at the bottom of the inlet section.*

2. • ***VORTEX FINDER:*** *Each MET-PRO unit can be modified to meet changing needs by varying the diameter of the vortex finder to modify the size of particle separation as well as capacity.*

3. • ***APEX OPENING (UNDERFLOW):*** *Apexes can be constructed of either urethane or refrax material depending on the application. The apex can be changed to meet underflow tonnage capacity.*

• ***UNDERFLOW REGULATOR:*** *The MET-PRO Maximum Density Separator has an underflow regulator in conjunction with the vacuum control system established by the overflow leg which can be set to produce a percent solids underflow that is most desirable for a particular need or application.*

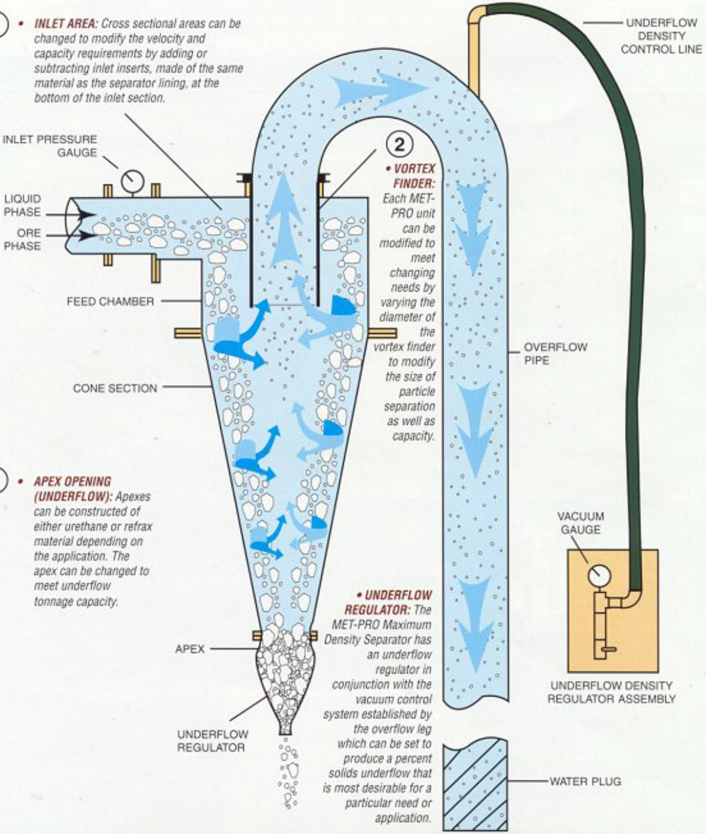


Figure 1. Typical maximum density separator (MDS)

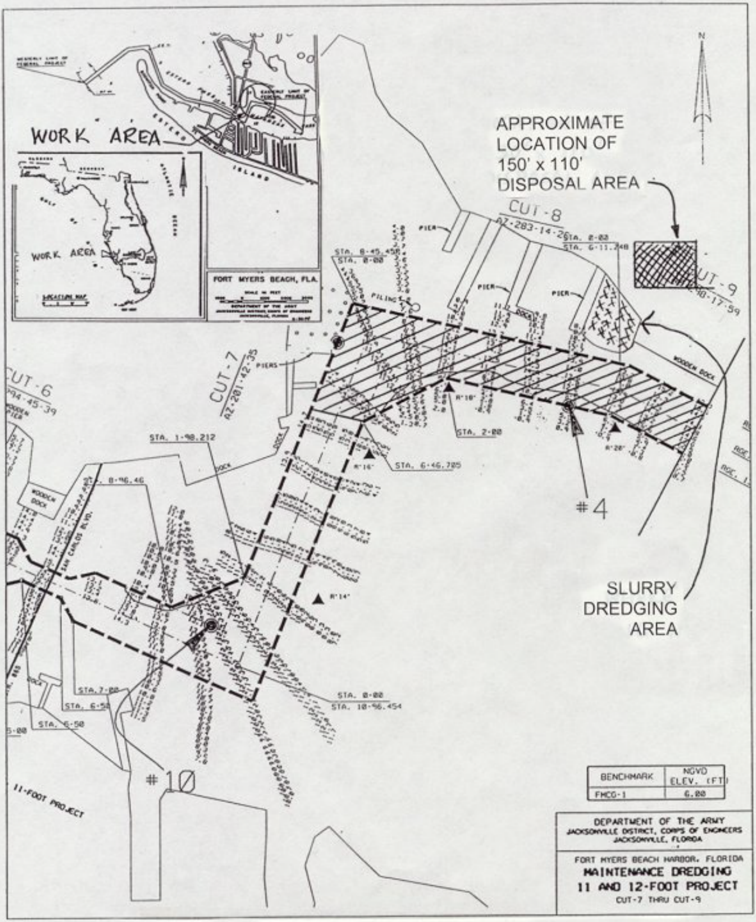


Figure 2. General location map

Figure 3. Bulk, underflow, and overflow samples

Figure 4. Hand comparison of underflow and bulk sample

Figure 5. Barge staging area

Figure 6. Close-up of barge and slurry dredge pump

Figure 7. 6-inch and 12-inch MDS and retention dike

Figure 8. Close-up of 6-inch and 12-inch MDS apparatus

Figure 9. Plan view of automatic level control (ALC) sump

Figure 10. Overflow slurry discharge into retention site

Figure 11. Resulting underflow sand pile

Figure 12. Graphical grain-size distribution summary

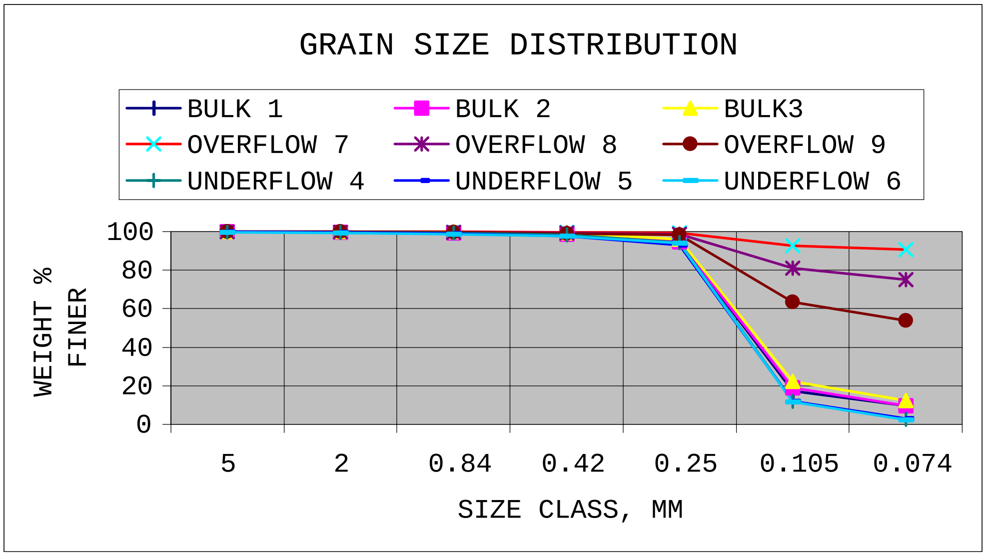
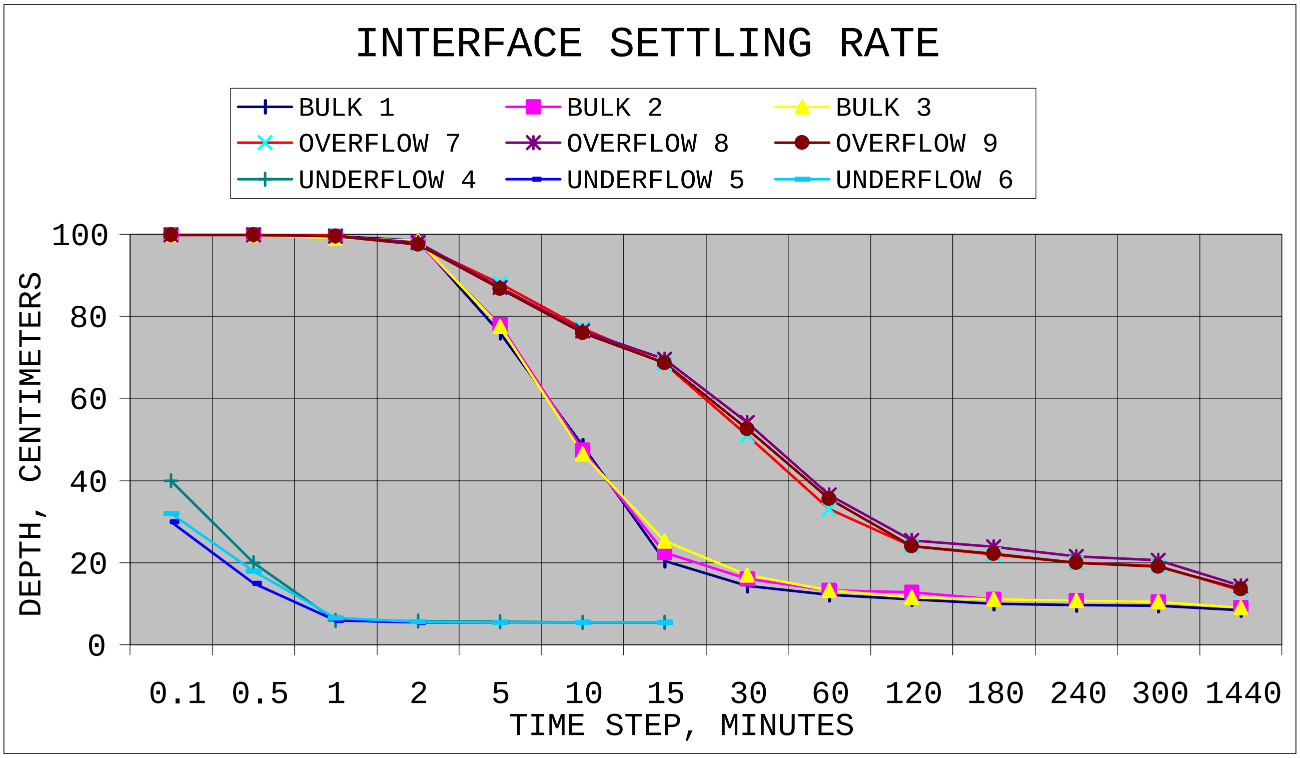


Figure 13. Graphical interface settling rate summary



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